peters

Coating Innovations for Electronics

REPORT

Conformal coatings, solder resists and casting compounds – optical requirements and performance in LED applications

Dr. Manfred Suppa
Holger Leiner
Johannes Tekath

Table of Contents

Abstract

Light emitting diodes (LED) are incorporated in a growing number of applications, and it is expected that they will continue to replace conventional light sources in more and more areas. Depending on their intended use, reflective, diffusing or light-absorbing properties are required for the the printed circuit board as a direct support of LED components, or respectively, for the solder resist as substrate surface. Moreover, the necessity of insulating the assembly by conformal coatings or 2-pack casting compounds is determined based on the later application of the assembly. Such conformal coatings or 2-pack casting compounds should not affect the optical properties of the LEDs in the long run, even if a protection is provided. This report deals with the following aspects of using conformal coatings for circuit carriers in combination with LEDs:

- What are the optical requirements for the substrate surface? How can these requirements be fulfilled by different conformal coatings to form the "surface finish"?

- Which classical criteria of coating technology, testing and evaluation standards can be used for an optical characterisation? Are there any specific demands that need to be considered? What are standard results? These aspects are discussed in detail, in particular with regard to the colour stability or yellowing resistance of various white solder resists, by considering different conditions of processing and testing.

- Are there any particular requirements of these coating systems in terms of processing compared to conventional applications? What do typical solutions look like?

- In which applications can clear-transparent 2-pack casting compounds based on polyurethane be used for "LED covering" when combined with effect additives? Which experience was made in the past regarding long-term stability under various conditions of operation? In this report, studies on storage temperature and UV-resistance or weathering resistance will be discussed in detail.

General information on colour physics

As a matter of fact, there is no colour at all in (inanimate) nature; colour is actually what is generated by our eye as a sense organ, or truly speaking, by the brain creating an impression of colour. Our visible light is an electromagnetic radiation of wavelengths between 380 and 760 nm approximately. This range is referred to as the visible spectrum which, in its entirety, appears to us as white light. The light's chromaticity can be observed in nature when a rainbow is created because of refracting light in water drops, breaking down sunlight into its spectral colours.

Light is perceived as a so-called colour stimulus by the retina of the human eye and is further processed by the brain to become a colour sensation or colour impression. Via a lens system with shielding (pupil and iris) the light enters the eye where it is received by the retina. The retina is a layer of sensory cells that transforms the light into electrical pulses, followed by their transmission to the brain by the visual nerve. There are two different types of sensory cells: the so-called rods are responsible for light and dark vision while the cones ensure colour vision. Among the cones, again, there are three different types which respond to different wavelengths of light.

Why make this excursus into the biology of our eye? As a sensory perception, colour is a subjective matter, in such way that a visual evaluation of colour is always imprecise and thus difficult to describe for reproduction. What is more, our eye-brain-system tends to correct the colour impression. Whereas light from the light bulb is perceived as "white light" when we are in the room, it looks distinctly yellowish when viewed from the street. A colour evaluated under artificial light may thus be quite doubtful. With regard to light sources, colorimetry distinguishes between various (standardised) types of light likely to influence the colour values measured. For example, D 65 is used to describe "standardized" sunlight or daylight, while light from the bulb is characterised by A or the light of a fluorescent lamp by F2. In this context, D 65 is referred to for measuring light.

The reflectivity of surface areas

Bodies may either reflect, disperse or absorb electromagnetic radiation, depending amongst others on the wavelength. With reference to visible light this means that a body that fully absorbs in the wavelength of between 380 and 760 nm does not reflect any radiation likely to provoke a sensory impression in the eye – this object is black. A body that sends back all incoming wavelengths (of white light!) appears to be white.

The key characteristic of an "optical" surface area is the reflectivity which is defined as the light remitted - diffused - by a body. Perfectly white objects display an even reflectivity of all wavelengths by 100 %, while black objects do not reflect at all. Perfectly grey objects display an even reflectivity of the wavelengths between > 0 and < 100 %, while coloured objects reflect selectively, meaning they partially absorb the light with the result that the remitted light only consists of a few wavelengths, thus giving the impression of colour. Figure 1 is the reflectivity graph of a white photoimageable solder resist with a reflectivity rate of more than 90 in the colour-relevant spectrum between 460 and 700 nm.
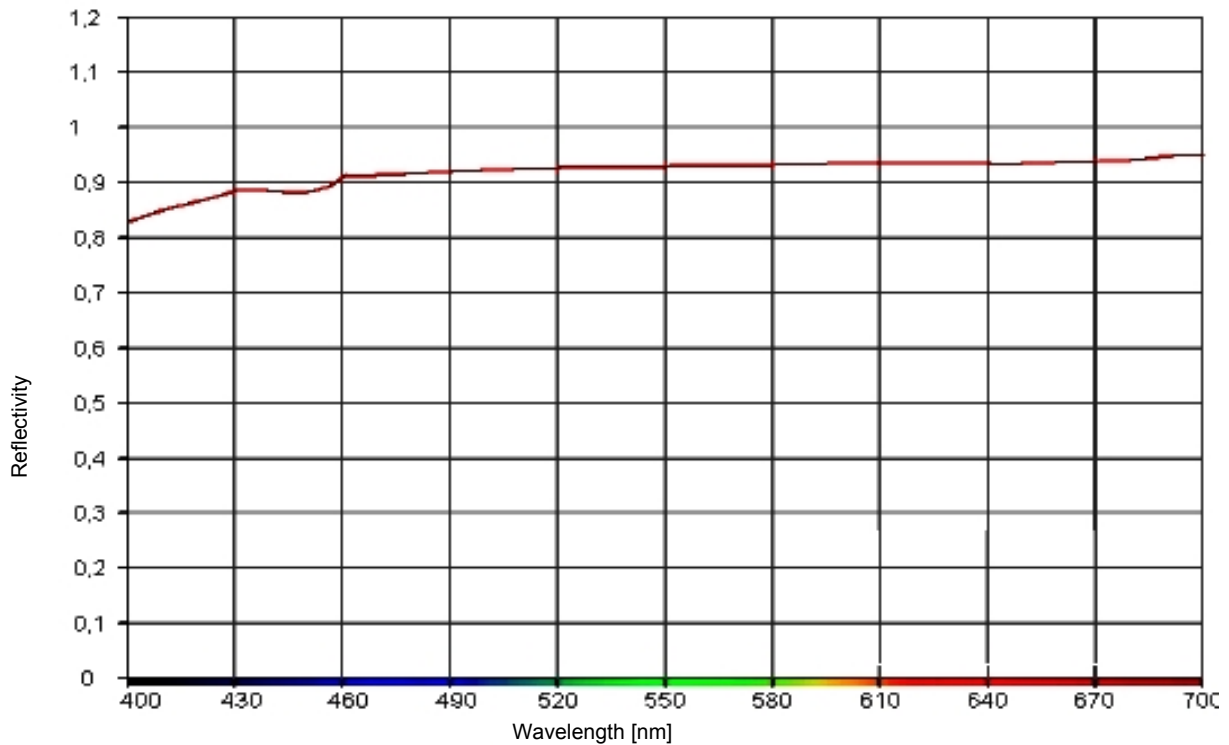
Fig. 1: Reflectivity graph of a white photoimageable solder resist
(source: Lackwerke Peters GmbH + Co KG)

Measuring colours – colorimetry

In order to describe a colour or a difference in colour from a quantitative point of view, one can il-luminate the surface to be measured by means of a defined light source and measure the light that has been remitted. In mathematical calculations, both the type of the light source and the colour impression of the eye is considered for measuring "colour". To characterise a colour through val-ues, the so-called CIE Lab System (to be precise, the L*-, a*-, b*-System der CIE – Commission internationale de l'éclairage, International Commission on Lumination) is commonly referred to. This Lab System is based on the transformation of the primarily calculated colour values X, Y, Z to the coordinates L* (brightness), a* (red-green-value), and b* (yellow-blue-value). This Lab System is based on the transformation of the primarily calculated colour values X, Y, Z into the coordinates L* (brightness), a* (red-green-value), and b* (yellow-blue-value). The deviation of the Lab values shall be dispensed with here while reference is made to [1].

The major benefit of the CIE lab system is its suitability for determining colour distances. The value defining a colour distance i.e. the similarity or identity of colours, is ΔE^*, which is calculated as a spacial Pythagoras from the three values $L_1^* - L_2^*$, $a_1^* - a_2^*$ and $b_1^* - b_2^*$:

$$\Delta E^* = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2}$$

In view of describing a white surface one can either use the reflectivity graph (see figure 1), or the brightness value L* from the CIE lab system. According to the definition, a perfectly white surface would have the coordinates L* = 100, a* = 0 und b* = 0. As an advantage, the CIE lab system re-stricts the values to be measured to no more than three figures and provides the option of forming differences that largely correlate with the colour perceived.
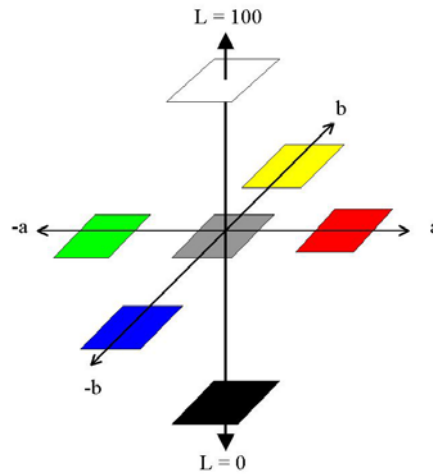
Fig. 2: Scheme of the CIE-L*a*b* system and its colour coordinates

Colorimetric measurings are very common in the conventional lacquer industry and are suitable as a quality criterion for specifying deliveries and goods' properties, such as weather resistance and/or temperature stability.

Besides an evaluation in accordance with the CIE lab system, there is also the possibility of defining colour changes – i.e. yellowing - as it is practised by the paper industry according to DIN 6167. Based on DIN 6167:1980-01, one speaks about yellowing if a non-desired yellowing value is recognised with the material observed, in consequence of its handling. From the primarily calculated X, Y and Z values a yellow value G is obtained. The change of the yellowing degree between an untreated (G_0) and a treated specimen (G_1) is calculated and referred to as the yellowing value V.

The colour coordinates of the Lab system i.e. the values L*, a* and b* can be directly measured by means of colorimetric devices. To obtain the yellowing value G specific software tools are actually required, or they can be calculated based on the X, Y, Z coordinates.

Colorimetric devices are composed of a light source, a measuring head with its different geometries and a detector such as a spectrophotometer. Among the methods available for measuring, only the spectrophotometer is suitable for recording a reflectivity graph of the desired wavelength range between 380 and 760 nm. To determine the colour coordinates, two basic measuring geometries are available: 45°/0° and d/8° (Ulbricht sphere); they can be easily combined as shown in the measuring setup (figure 3). For the studies described below the d/8° measuring geometry and an Ulbricht sphere with gloss trap were used.
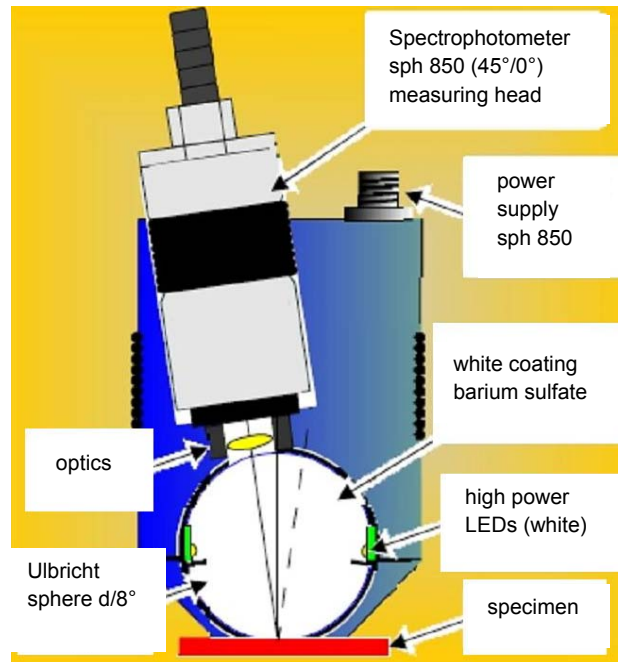
Fig. 3: Scheme of the measuring head adapter using the d/8° geometry (Ulbricht sphere)
(source: ColorLite GmbH)

When applying the two methods sketched, a value of difference is obtained. The smaller the differ-ence i.e. yellowing value V, the lower is the yellowing effect or, respectively, the colour change. This same statement, however with a different weighting, is achieved by defining the difference values ΔE*, ΔL* or Δa* using the CIE lab system. The yellowing issue as well as colour measuring is discussed in detail in [1].

For evaluating the results obtained by measuring we suggest to apply a scale originating from the field of white radiator enamels; in this context five quality levels were specified:

The highest quality level (lowest yellowing effect) is indicated by a yellowing value < 1. The grading levels of lower qualities correspond to the yellowing rates of < 3, < 5, < 8 and < 10. Moreover, the following information is given on yellowing values (V):

V = 0–1:   not visible in general

V = 1–2:   low yellowing, only visible by the trained eye

V = 2–3,5: medium difference, visible by the untrained eye

V = 3,5–5: distinct difference

V > 5:   strong difference

This assessment can also be transferred, in good approximation, to the interpretation of the pre-cited ΔE*, ΔL* and Δa*-values. Given the wide spreading and acceptance of the AE*, ΔL* and Δa*-values for describing colour distances and/or colour changes, it is recommended to apply these data. Figure 4 shows a typical L*, a*, b* evaluation of three different white solder resists permitting a detailed interpretation of colour changes via physical measuring – in connection with the values measured.

Conformal coatings, solder resists and casting compounds –
optical requirements and performance in LED applications

CIE L*a*b* colour space

	L*	a*	b*
Standard	93,57	−0,33	1,18
Probe	91,79	−0,31	1,97

■ coating 1: SD 2496 TSW after reflow soldering
■ coating 2: SD 2491 SM-TSW after reflow soldering
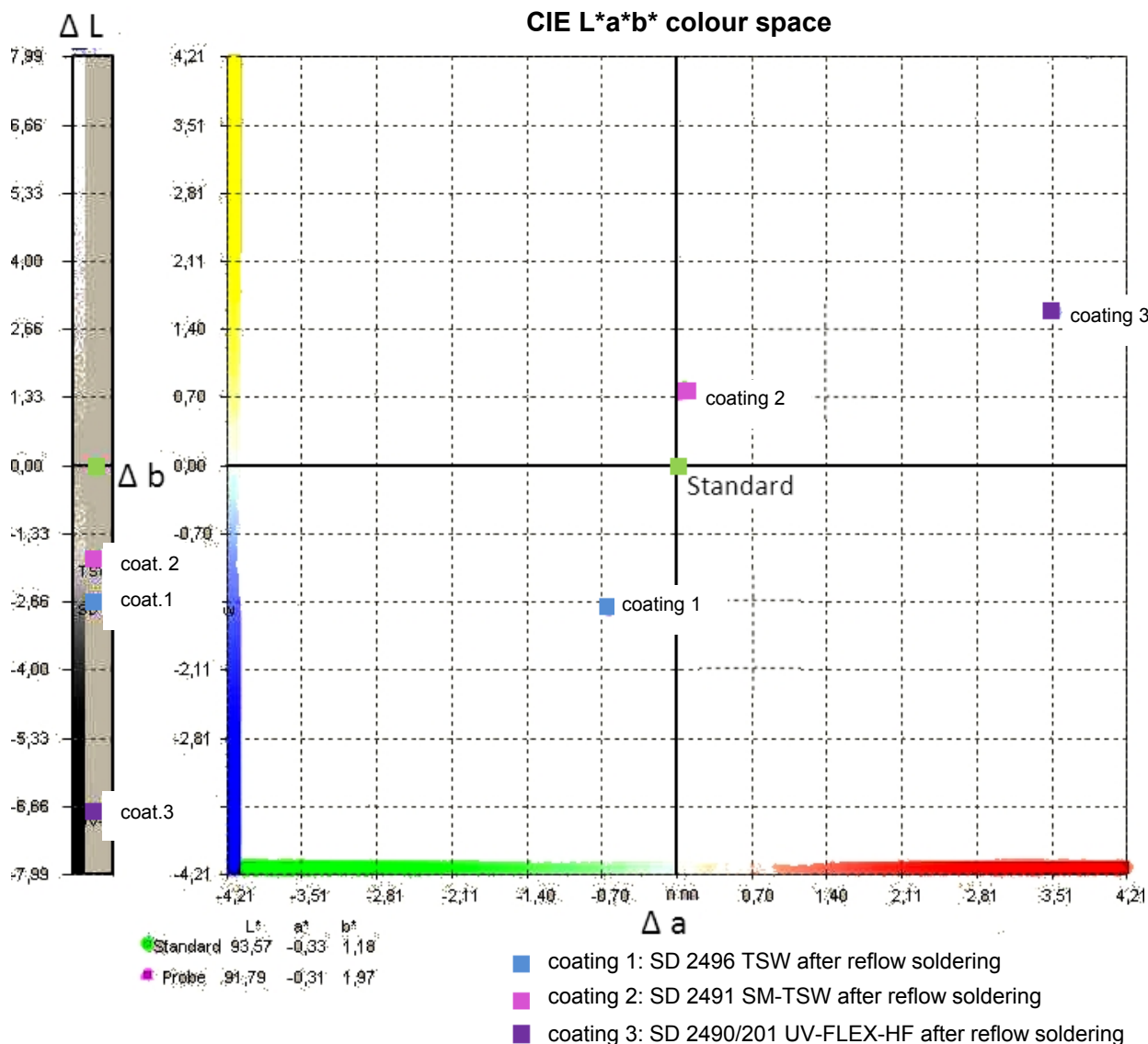■ coating 3: SD 2490/201 UV-FLEX-HF after reflow soldering

Figure 4: Example of an L*, a*, b* evaluation of three white solder resists
The distance to the origin is a colour distance measure

Another basic feature of coloured coating materials is the so-called covering power which indicates the performance in covering the colour, or colour difference, of the base material. As a criterion, a contrast ratio is predefined between the contrasting areas of the basis. The covering power is achieved by absorption and diffusion and is a function of the colour-giving pigments. In case of white pigments, it is only a consequence of diffusion. The covering power depends on both the layer thickness and the respective contrast with the basis and has a characteristic limit. The covering power cannot be adapted to any thinness of layer. The minimum layer thickness required for a white covering coating in a black-white contrast is approx. 40 µm. Unlike thermal curing solder resists, UV curing coating materials – including photoimageable solder resists – must be slightly transparent in order to ensure a sufficient UV crosslinking down to the substrate.

There are certain consequences for processing, given the physical limits of the covering power. This way, a 10 µm thick layer looks less white than a layer of 20 µm, and again a 30 µm layer seems to be whiter than a 20 µm layer. Only for a layer thickness of approx. 40 µm or higher, the white colour no longer depends on the layer thickness since covering power has been reached. Within colour evaluations and measurings of a layer thickness below covering power, i.e. lower than approx. 40 µm, the base material has to be included in the evaluation. This means that the reflectivity graph and the L* value also depend on the layer thickness (figure 5).
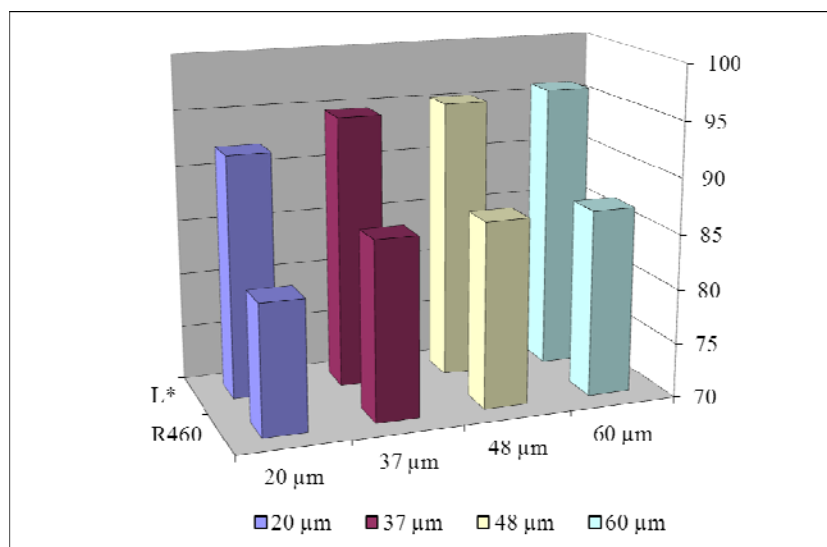
Figure 5: The reflectivity or L* value of a white solder mask depending on layer thickness
(source: Lackwerke Peters GmbH + Co KG)

Figure 6 shows the same basic facts in the reflectivity graph as an example. A white photoimageable solder resist was applied on copper in different layer thicknesses and then measured. One can clearly see the lower reflectivity at 20 µm layer thickness due to lack of covering power.
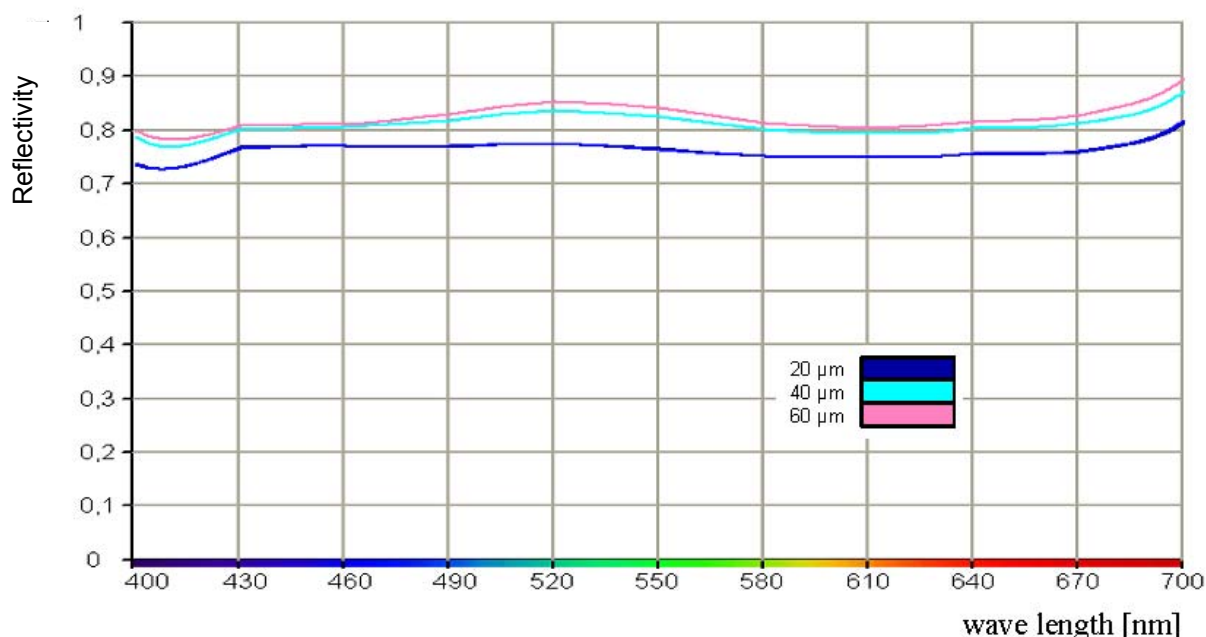

Figure 6: The reflectivity of a white solder mask (ELPEMER SD 2491 SM-TSW-R1)
depending on layer thickness, on copper basis (Source: Lackwerke Peters GmbH + Co KG)

Solder resists on LED circuit carriers

With the growing usage of SMD-LEDs for illumination and the demand for a better luminous efficacy it is more and more specified that the circuit carrier shall remit the light falling inevitably on it in an optimum manner. Reflectivity is the diffuse reflexion of radiation (light). In general, the circuit carrier is covered by a solder resist which besides the electrical isolation properties and chemical resistance must fulfill additional new functions in such cases.

For a white solder resist, these may include the reflectivity of an application in terms of background lighting, or a high colour stability under sunlight and/or heat exposure.

The solder resist should be white, but the simple term "white" does not describe the actual requirements to be fulfilled, such as an optimum reflectivity. Reflectivity is closely linked to coulour and can be expressed in figures via colorimetric measuring, as explained above.

For this type of application, only specifically developed solder resists are capable of fulfilling high demands in terms of whiteness, reflectivity and colour stability under temperature loads and/or sunlight exposure.
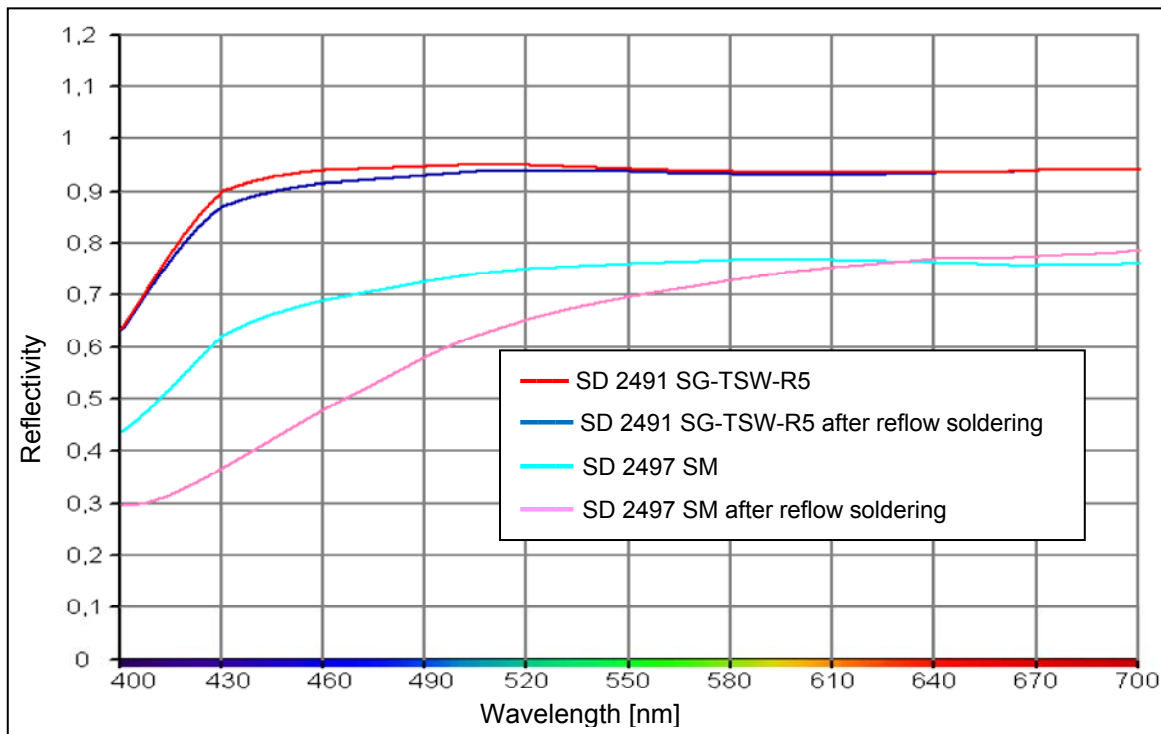

Figure 7: Reflectivity graphs of a classical photoimageable solder resist (SD 2497 SM) and one
of the new generation (SD 2491 SG-TSW-R5) before and after reflow loading
(source: Lackwerke Peters GmbH + Co KG)

When processed, solder resists undergo several thermal loads which may have a visible impact on the (white) colour. This is particularly valid for the soldering process which causes a shift towards the yellow colour i.e. yellowing. A white solder resist supplied to the assembler should undergo the least possible colour change in subsequent solder processes.

As for the underlying mechanism, there are different causes for yellowing:
- heat,
- sunlight,
- environmental influences (e.g. humidity, chemicals).

In this context, it is primarily yellowing by heat or sunlight, or by a sunlight simulating time lapsed UV radiation that takes place. Light-induced yellowing is produced whenever light beams fall on polymers with a wavelength of less than 380 nm (UV radiation). So-called chromophore groups producing a discoulouring are created through radically induced photochemical reactions. Heat-induced yellowing is the formation of such chromophore groups that are produced when polymers are exposed to temperatures > 100 °C for a longer period of time.

The colour change can be expressed by the so-called yellowing value on the one hand, or by measuring the colour distance in the CIE lab system on the other.

In order to define this colour change the previously described colour distance ΔE* can be applied. The two values ΔL* and Δb* shall be given particular attention in case of purely white surfaces. While ΔL* describes the change of brightness, Δb* defines the blue-yellow-shift i.e. the yellowing effect in this case (see figure 4 on page 5). The Δ value, as low as possible, stands for the quality of the solder resist's colour stability, with differences of less than 0.5 being hardly perceivable for the untrained eye.
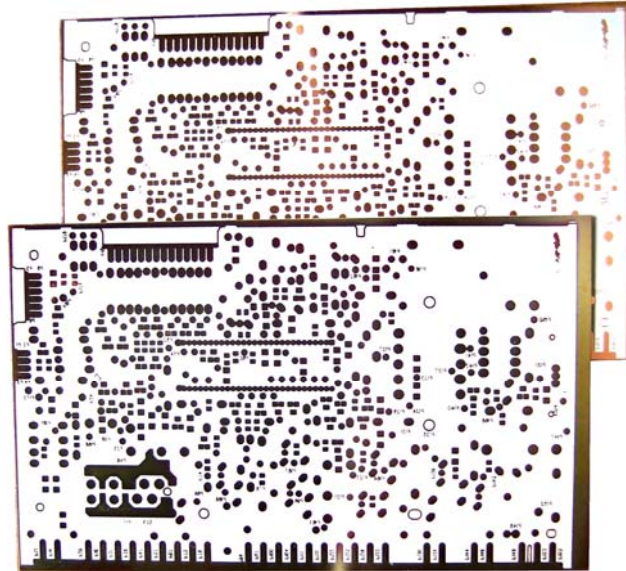

Figure 8: Temperature-stable white photoimageable solder resist before (top)
and after a triple reflow simulation (bottom)
(The discolouring of the solder resist shown in the figure only serves as orientation;
An exact colour rendering is hardly possible in print media.)
(source: Lackwerke Peters GmbH + Co KG)

In the lower picture, figure 8 shows a printed circuit board coated with photoimageable solder resist after a triple lead-free reflow loading, while the same board prior to the reflow process is shown in the upper picture. With a brightness value of L* = 93, this surface features a very good reflectivity. The colour differences ΔL* and Δb* of < 1 indicate a very good colour consistency even after temperature loading.

As a general statement, it was established that a colour change resulting from heat exposure i.e. thermal yellowing, is primarily provoked by oxygen. This way, solder processes performed without oxygen revealed distinctly less yellowing than those under air. However, this effect is no longer visible with the solder resists of the youngest generation (figure 8).
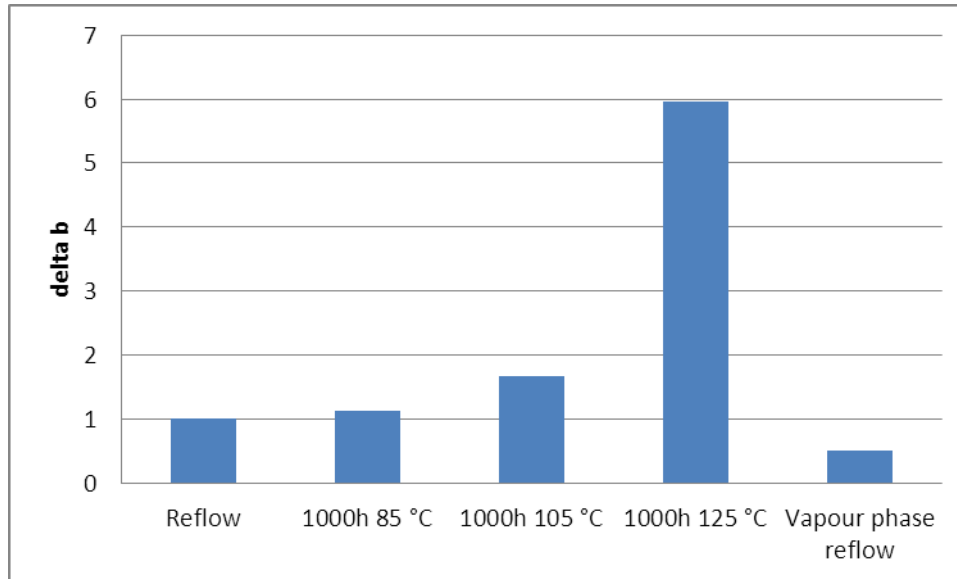
Figure 9: Colour change of a solder resist after one reflow soldering process, vapour phase soldering and temperature storage at various temperatures displayed as Δb.
(source: Lackwerke Peters GmbH + Co KG)

As briefly described, colour metrics is also very well suited for describing the colour behaviour after permanent temperature storage, besides for determining critical permanent temperature loads. Figure 9 shows the shift of the b* values which describe yellowing subject to different storage temperatures and two solder processes. A shift towards higher positive b values describes yellowing – here thermal yellowing. As expected, the red-green values a* have not changed; this is also revealed by the permanent temperature storage shown in figure 10. It can be clearly noticed that a permanent temperature resistance is ensured up to 105 °C. Here a temperature load of 125 °C provokes a distinct colour shift or yellowing. Colorimetric tests of this type are suitable for determining colour resistance subject to permanent temperature storage in accordance with the series of standards IEC 60216 [2] for example, and for defining a corresponding temperature index for optical properties.

Moreover, one can take from figure 9 that, for the solder processes in particular, it is not so much the temperature but rather the combination between temperature and air oxygen that provokes yellowing. This way, solder processes under nitrogen show a distinctly lower yellowing effect than those under standard ambient conditions.

The electrical performance of a coating is not affected by yellowing. Earlier studies did not reveal any changes of electrical properties related to yellowing.
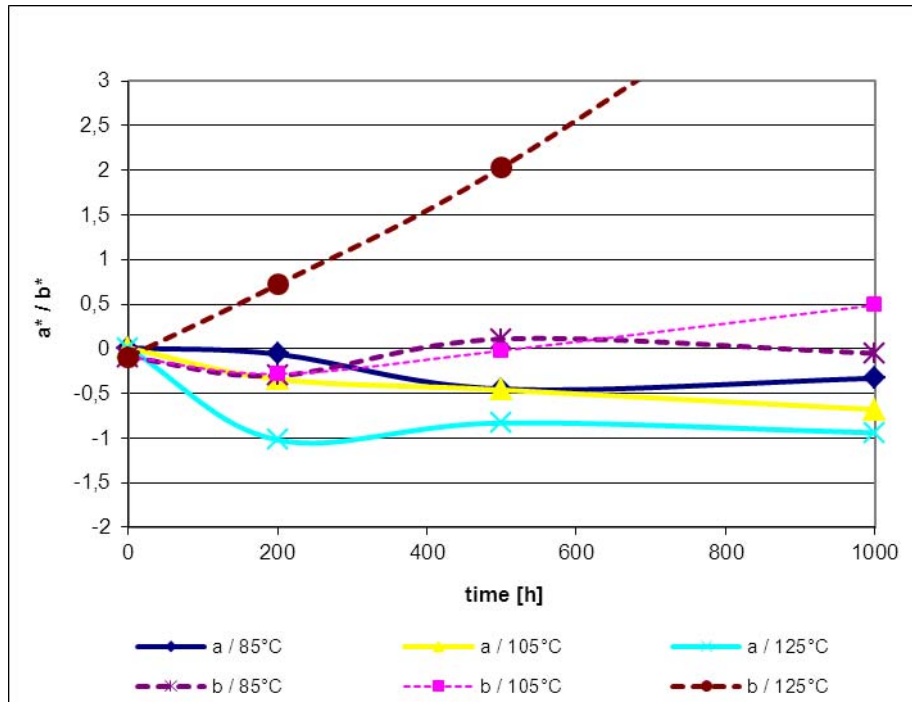
Fig. 10: Colorimetric tests on the yellowing of a white solder resist under different permanent storage temperatures
(source: Lackwerke Peters GmbH + Co KG)

Under exposure to global radiation – usually referred to as sunlight - many polymers show more or less distinct degeneration effects. Absorbing in the short-wave range of visible light, the final products of the so-called photo-oxidation are the reason for the yellowing process of polymeres. This yellowing especially affects epoxy resins that are commonly used for producing solder resists. In order to produce sufficiently light stable white solder resists, a different polymer class had to be chosen for manufacturing.

In order to measure the light stability or yellowing resistance, appropriate specimens can be stored in so-called natural weathering over years, for example within the so-called Florida test. Short-term results can be obtained by applying accelerated weathering tests, such as the so-called Xenon test. In this test, the specimen is exposed to the radiation of a xenon arc lamp; its filtered spectrum and irradiance are similar to natural sunlight. The corresponding short-term tests have been described by various DIN standards [3, 4]. As a rule of thumb, 250 h are about equivalent to one year of natural loading. In figure 11, the results of a colorimetric evaluation of various solder resists after UV exposure are shown as an example. The changes of the Lab values have been included in this graph as figures, for ease of presentation.

The yellowing is clearly noticeable by the change of the Δb value (db), while the brightness shift ΔL is much lower. After a XENON test of 1000 h, the three example solder resists showed excellent UV resistance, with the 2-pack solder resist being by far the most stable UV version. Photoimageable solder resists of the old generation were not considered here, their colour shifts of more than 3 are out of question.
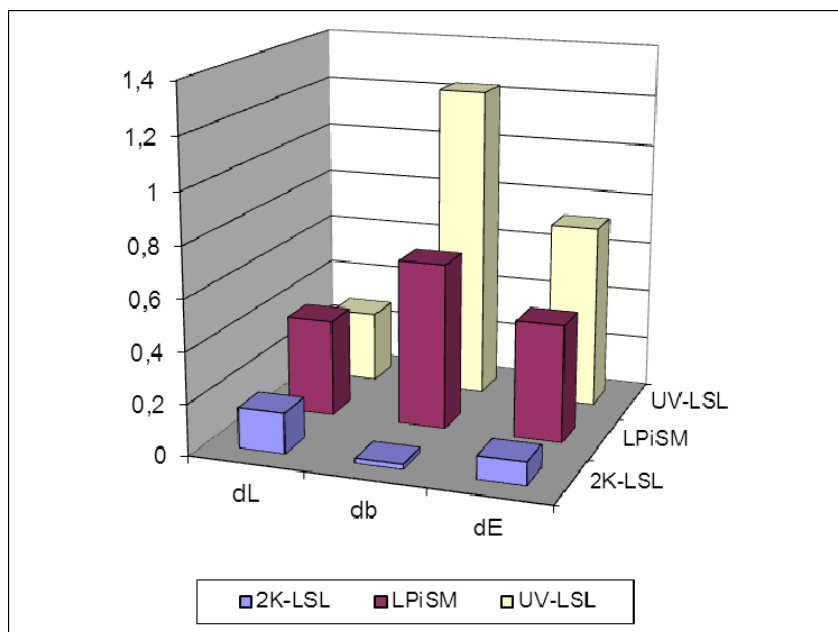
Figure 11: Colorimetric evaluation of UV yellowing by means of the XENON-Test[1] (1000 h),
example yellowing values of: UV-LSL – UV curing solder resist
LPiSM – liquid photoimageable solder mask
2K-LSL – 2-pack solder resist (source: Lackwerke Peters GmbH + Co KG)

As expected, tests carried out based on an LED light radiation of 460 nm wavelength during 1000 h show a change of reflectivity that cannot be visually detected or measured. Any impact is rather expected from simultaneous heat input likely to cause heating up to 100° C, than from the light received.

Conformal coating of LED carrying assemblies

The conformal coating may either be applied over the complete circuit carrier or in areas where no LEDs were mounted.

In case that LEDs are overcoated, the coating the conformal coating has to fulfill, besides electrical isolation under harsh environmental conditions, the requirements of a high optical performance which include yellowing and gloss resistance.

Another possibility of protective coating is provided by white covering coatings which are applied by means of selective coating, leaving out LEDs. This method, for example, allows a good coverage of dark-coloured components on single-sided LED assemblies. Protective or finishing coatings of this type exhibit a high light stability and heat resistance along with very high reflectivity ratings, as displayed in table 1 on the example of a solvent-containing white finishing coating which features, at the same time, good electrically insulating protection functions.

Property	No loading
Reflectivity rate R_{460}	0.92
Brightness L*	97
Red-green-value a*	-0.59
Yellow-blue-value b*	4.48

Table 1: CIE-Lab values of a white finishing coating applied on LED circuit carriers

---

[1] in acc. with DIN EN ISO 11341 with Suntest CPS+, no moisture loading, irradiance: 550 W/m²

If boards assembled with LEDs are to be coated completely, in view of protecting them against humidity, a type of conformal coatings would be chosen that, on the one hand, ensure electrical insulation under various ambient conditions, and on the other exhibit a low risk of yellowing under such loads as far as their weather resistance is concerned.

The measuring results of transparent specimens by colour metrics cannot be compared with traditional reflectivity results of white coatings, for example. While in case of colour measurings of couloured coating materials it is primarily the reflectivity properties that stand out, the transmission or absorption properties stand out for transparent coating materials. Within the measuring process, the body is penetrated by radiation down to the reflecting substrate, and once again down into the measuring sensor (Ulbricht sphere).

Potting of LED carrying assemblies

Owing to the the growing usage of sensors especially in outdoor applications, the resistance of casting compounds against weathering and sunlight in particular is demanded, as well as high transparency.

The potting of LED carrying assemblies makes it necessary to review the chemical basis of casting compounds. Standard casting compounds based on polyurethane resins do not formulate polyisocyanate that accounts for weather- and sunlight-resistance.

Alike thermal loads, long-term weather and UV loads cause so-called ageing processes which may also be divided, form a physical point of view, in three groups of properties as shown in figure 10:

- Change of mechanical properties,
- Change of electrical properties,
- Change of optical properties.

The properties of optical relevance include colour coordinates, spectral reflexion coefficient, absorption coefficient and gloss. Without going into photochemical details, one may say that the change of colour position, usually referred to as yellowing, is provoked by the formation of so-called chromophores[2]. In case of polymers, extended conjugated double bond systems are formed which absorb the radiation of long-wave visible light and thus produce colour impression. In consequence, yellowing is a visible chemical change of the polymer structure.
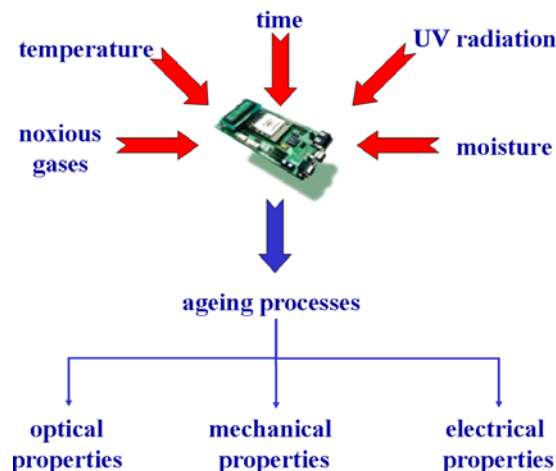

Figure 12: Causes and effects in ageing processes

---

[2] chromophor (Greek) = colour carrier

Owing to their chemical basis, standard casting compounds do not exhibit sufficient resistance against sunlight, i.e. against the UV light component of sunlight. Here one must choose specific polyurethane materials. However, to date, this type of specification has not been incorporated in the standards yet. Any individual requirements would have to be checked with the supplier.

Classical 2-pack epoxy pastes undergo surface changes when exposed to weathering. As a consequence, chalking and reduction of gloss starts to appear. UV radiation and humidity will attack the top layer of the binder and degrade it, thus releasing pigments and filler particles which will first reduce the gloss and later on degrade pigments and fillers. This degrading of the surface, however, is very neglectable in relation to the overall thickness. The first chalking effects occur about 3 to 6 months later, depending on weathering conditions. The reason for chalking and gloss reduction lies within the aromatic structure of epoxy resins, with influences of hardeners being of minor importance. By the same token, yellowing provoked by nothing else but sunlight may occur. The degree of yellowing will depend on the hardener.

Standard polyurethanes usually cured with aromatic hardeners react in the same way. This degrading is even reinforced if the resin component is a so-called polyether. Only specific resin systems where an aliphatic isocyanate prepolymer crosslinks with specifically selected polyoles, exhibit an appropriate resistance. Short tests for weather and UV resistance are used by the lacquer and plastics industries (e.g. Xenon test, QUV test, weather-o-meter); however, the results have to be interpreted with caution. To accelerate the degrading process, these methods use UV parts in the test cycle that do not exist in realistic outdoor loads, and where there is no direct correlation with the desired weathering and UV resistance. Realistic outdoor weathering conditions should be preferred if time permits. Under so-called short-term weatherings, short-wave UV radiation applied in addition to the sunlight spectrum may cause photochemically induced degrading reactions in the molecule which would not appear in reality.

UL 746C [5] too, describes a test cycle for an outdoor application of polymers. It specifies that a polymer has to be pre-damaged by:

- 720 h UV loads
  or
- 1000 h in Xenon weatherometer
  and/or
- 7 days of water immersion at 70 °C.

These studies and tests focus on potential impacts of the basic mechanical properties of polymers. In embrittlement processes provoked by weathering – so called pre-damages – the non-flammability property must not change, while mechanical properties may changed by 70 or 50 % as follows:

Property	UV load	Water immersion
Non-flammability class	unchanged	unchanged
tensile or bending strength	70 %	50 %
impact strength, Izod or Charpy impact strength	70 %	50 %

Table 2: Criteria for the change of polymer properties in outdoor applications in acc. with UL 746C

These criteria surely cannot be applied to optical requirements, since the requested property changes, for example with regards to yellowing, would have to be defined much more narrowly. However, attention has to be paid to mechanical characteristics which will also change under UV loading.

With regard to transparent materials it should be noted that the measurings are performed, for example, on colour-stable white substrates, and that the result is not a pure reflexion value as in case of coated specimens, but rather a transmission value. This means that the colour impression corresponds to the rate of transmission i.e. the absorption of the radiation measured. The transmission rate is dependent on layer thickness: The thicker the layer, the more light will be absorbed, and the more intense will be colour impression. What makes it even more complicated is the fact that with transparent materials, yellowing does not occur evenly over the layer thickness; yellowing has the shape of a gradient, meaning that it decreases in the direction of the substrate.

Deviating from standard DIN 6167, yet physically reasonable is the fact that a yellow value can be obtained, in particular with transparent materials, by measuring the spectral transmission values of the wavelengths 450, 550 and 600 nm.[3]

The characteristics obtained this way are to be understood and applied as a quality criterion; such values are less suitable for providing detailed information on the optically perceived colour location. In this case, a calculation of the changes for brightness values (ΔL*) and colour values (Δa* and Δb*) from the CIE lab system is more significant. The evaluation of the above-mentioned changes of the yellowing value V is equivalent to an evaluation in ΔE^*_{ab}.

Under temperature loads and/or humidity loads heat-induced colour changes may occur in the polymer, as decribed above. If optical properties are to be evaluated, they can be described accordingly by a yellowing value.

In this context, the thermally induced yellowing is no measure for the mechanical destruction of the coating material. This way, a slight yellowing may entail major changes of structure and embrittlements, while a strong yellowing causes almost no change of properties [6] at all.

Transparency and opacity

The transparency and characteristics discussed above are considered to be optical properties of materials, with transparency being the property of a material to let through electromagnetic radiation, also referred to as transmission. This is generally true for any kind of electromagnetic radiation such as radio waves, IR radiation, X-rays or visible radiation i.e. light.

As a matter of fact, some materials may be opaque for visible radiation while being transparent for other wavelengths, as known from X-rays. If the transparency changes within visible light, this means that the transparent material is tinted i.e. coloured.

In contrast to transparency, any partial light transparency, e.g. of wax, milk glass or parchment, is referred to as translucence, with the reciprocal property being opacity. A material of high translucence – light permeation – has a low opacity. Opacity or turbidity is a light diffusion that is independent of the wavelength in the visible range.

Transparency is related to transmission which describes the permeability of a material – gas, liquids or solids. From a quantitative point of view, this characteristic is described by the transmission rate T or τ which is a measure of the intensity of permeation. A reduced level of intensity is absorption. If one considers the absorption of a material in relation to its layer thickness one is faced with the Lambert law (see also figure 13). For the permeating intensity I of a layer thickness s, the Lambert-Beer law applies:

$$I(s) = I_0 \cdot \exp(-\mu \cdot s)$$

---

[3] see also: DIN 6167:1980-01 Description of the yellowing of almost white or almost colourless materials.

µ is the absorption coefficient which is a material-specific value on the one hand, and also dependent on the wavelength on the other.
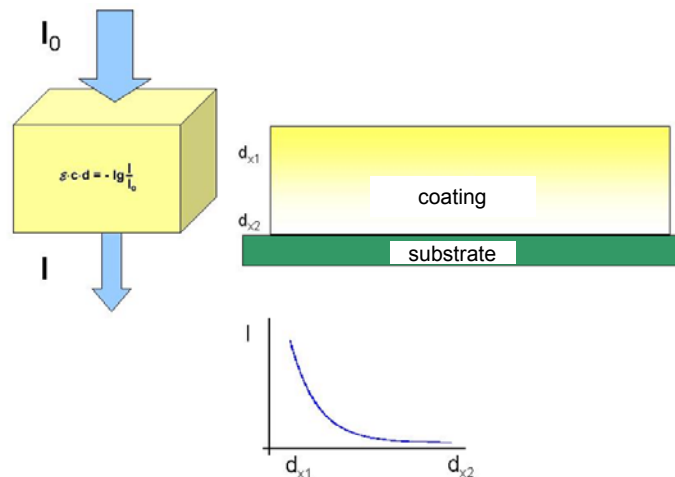

Figure 13: Light permeability of transparent materials and their dependency on layer thickness

This exponential dependency on layer thickness is of importance in comparative evaluations and/or characterisations, or if one applies results from the test layer thickness on the later layer thickness of the application.

The yellowing of transparent coating materials or casting compounds on white substrates can be performed by means of the colour metrics method described above. In this case, the basic conditions briefly laid down in the chapter "Conformal coating of LED carrying assemblies" have to be observed and considered when the colorimetric values are analysed. When proceeding to a colorimetric evaluation, it should be noted that in case of colour measurings over a white substrate, there are additional effects of dispersion besides the pure colour change, and that the specimen contributes twice to absorption. By means of a UV VIS spectrometer, optical requirements such as the transmission rate can be measured directly, however, it is impossible to convert the results into the values describing colour changes. The description of transparency and yellowing provided here is limited to the description above and not discussed in detail. Nevertheless, colorimetric studies of transparent coatings or casting compounds generally permit a comparative evaluation of materials under identical conditions of testing.

Literature

[1] Loos, Hans, Farbmessung, Verlag Beruf + Schule, Itzehoe (1989)

[2] DIN EN 60216-1, VDE 0304-21:2002-09, Elektroisolierstoffe – Eigenschaften hinsichtlich des thermischen Langzeitverhaltens

[3] DIN EN ISO 11341:2004-12, Beschichtungsstoffe – Künstliches Bewittern und künstliches Bestrahlen – Beanspruchung durch gefilterte Xenonbogen-Strahlung

[4] DIN 6167:1980-01 Beschreibung der Vergilbung von nahezu weißen oder nahezu farblosen Materialien

[5] UL 746C Polymeric Materials – Use in Electrical Equipment Evaluations, Outdoor Suitability

[6] W. Berger, Untersuchungen zur Dauerwärmebeständigkeit von Anstrichen, farbe + lack, 72. Jahrg., S. 127–132 (1966)

[7] Zuverlässigkeit von fotostrukturierbaren Lötstopplacken bei Belastung durch Temperaturdauer- und Temperaturwechselstress, 14. FED-Konferenz, 21.–23. September 2006, Kassel